Heavy Flavor Measurements in Heavy Ion Collisions by PHENIX at RHIC

D. McGlinchey, for the PHENIX Collaboration

Department of Physics, Florida State University, 77 Chieftain Way, Tallahassee FL 32306-4350 USA

Abstract. Studying J/ψ production in Au+Au collisions provides insight into the color screening length of the QGP medium produced in heavy ion collisions. However, recent measurements in d+Au collisions show that cold nuclear matter effects are large, and understanding them is critical to the interpretation of the heavy ion data. We find that the new d+Au data requires a nuclear modification which is stronger than linearly or exponentially dependent on the nuclear thickness at forward rapidity. Extrapolating the cold nuclear matter effects to Au+Au collisions we find that, at midrapidity, there is suppression beyond cold nuclear matter effects, and that a similar statement at forward rapidity must wait for a full description of the d+Au data.

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MEASURING COLD NUCLEAR MATTER EFFECTS

A large suppression of J/ψ production in Au+Au collisions relative to $p+p$ collisions has been measured by PHENIX at both forward and midrapidity[1]. One of the puzzling features of the measurement is the greater suppression observed at forward rapidity relative to midrapidity, which is counter to predictions based on energy density arguments. One possible cause for this difference is the effects of J/ψ production in a nuclear target, often termed Cold Nuclear Matter (CNM) effects, which could vary greatly with production kinematics.

To extract these CNM effects directly, PHENIX has recently measured J/ψ production in d+Au collisions[2] from data obtained in the 2008 RHIC run. Figure 1 shows the measured nuclear modification of J/ψ production relative to $p+p$ collisions (R_{dAu}) as a function of rapidity integrated over centrality (0-100%). The data show increasing suppression with increasing rapidity, with up to 40% suppression at forward rapidity.

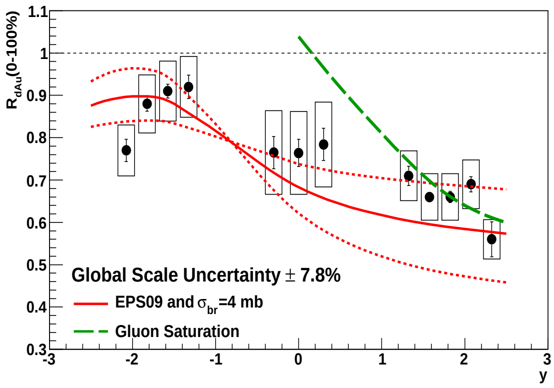

FIGURE 1. J/ψ nuclear modification relative to $p+p$ collisions (R_{dAu}) as a function of rapidity integrated over all centrality (0-100%) [2]. The curves in both figures are described in the text.

Also shown in Fig. 1 are predictions of the nuclear modification from two models. The red curves are calculations including nuclear shadowing using the EPS09 nPDF set [3] combined with an example breakup cross section of $\sigma_{br} = 4$ mb. The solid red curve utilizes the central EPS09 parameter set, while the two dashed curves use the EPS09 nPDF's for the largest variation. This shows good agreement with the data across all rapidity. The second model incorporates gluon saturation at small-x [4] and is shown as the green dashed curve in Fig. **??**. While the gluon saturation model shows good agreement with the data at forward rapidity, it predicts an increase in the modification at midrapidity that is not observed.

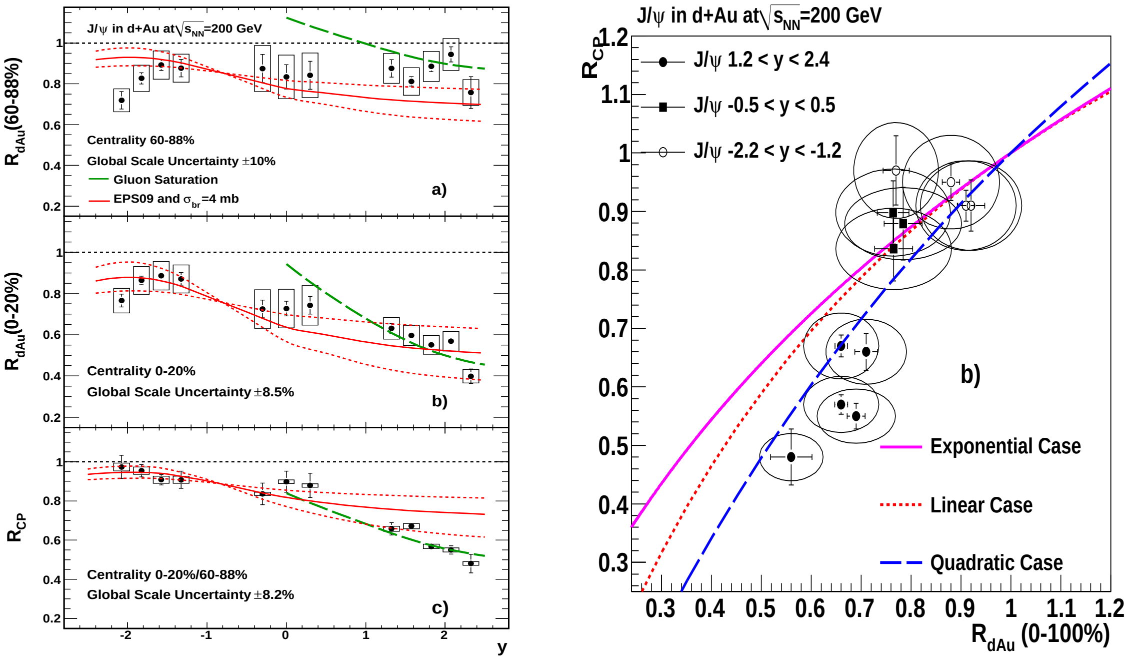

FIGURE 2. (Left) J/ψ R_{dAu} for peripheral collisions (a), central collisions (b), and R_{CP} (c) as a function of rapidity [2]. (Right) J/ψ R_{cp} vs. $R_{dAu}(0-100\%)$ along with exponential, linear, and quadratic nuclear thickness dependencies[2].

The J/ψ R_{dAu} vs. rapidity has also been measured as a function of centrality, and is shown in Fig. 2 for both central and peripheral collisions, along with the J/ψ nuclear modification relative to peripheral collisions (R_{cp}). R_{CP} shows similar behavior to central R_{dAu} but with cancellation of many of the systematic errors.

The EPS09 and gluon saturation model predictions for each centrality range are also shown, using the same conventions as detailed above. The EPS09 nPDF's contain no information about the centrality dependence of the modification, so a linear dependence on the density weighted longitudinal thickness through the gold nucleus at the location of the struck nucleon, r_T, $\left(\Lambda(r_T) \equiv \frac{1}{\rho_0} \int dz\, \rho(z, r_T)\right)$ is assumed. Here we see that while the EPS09 with a linear dependence on the nuclear thickness + $\sigma_{br} = 4$ mb describe the R_{dAu} data for central collisions well at all rapidities, it over predicts the suppression at forward rapidity for peripheral collisions. This disagreement is seen clearly in the comparison with R_{CP}.

To further investigate the centrality dependence of the d+Au data, three different forms of the nuclear modification as a function of $\Lambda(r_T)$, linear $(M(r_T) = 1.0 - a\Lambda(r_T))$, quadratic $\left(M(r_T) = 1.0 - a\Lambda(r_T)^2\right)$, and exponential $\left(M(r_T) = e^{-a\Lambda(r_T)}\right)$, each with one free strength parameter a, were tested. The nuclear modification factors are then calculated by coupling a given modification function, with a given value of a, with r_T distributions of the PHENIX centrality bins obtained from a Glauber model of d+Au collisions. For any given form of the modification, a single value of a gives a unique relationship between R_{CP} and $R_{dAu}(0-100\%)$. Varying a for a given form of the modification will create a locus of points on the R_{CP} vs. $R_{dAu}(0-100\%)$ plane, on which any suppression with that geometric dependence must lie. The results for the three functional forms of the modification chosen above are shown in Fig. 2, along with the data.

Figure 2 shows that the backward and midrapidity data are unable to distinguish between the three forms of the modification chosen, while neither linear or exponential dependence on the nuclear thickness fits the forward rapidity data. This is why the EPS09 with an assumed linear dependence on the nuclear thickness + nuclear breakup (which is exponentially dependent on the nuclear thickness) is able to describe the backward and midrapidity data, but unable to describe the centrality dependence of the forward rapidity data.

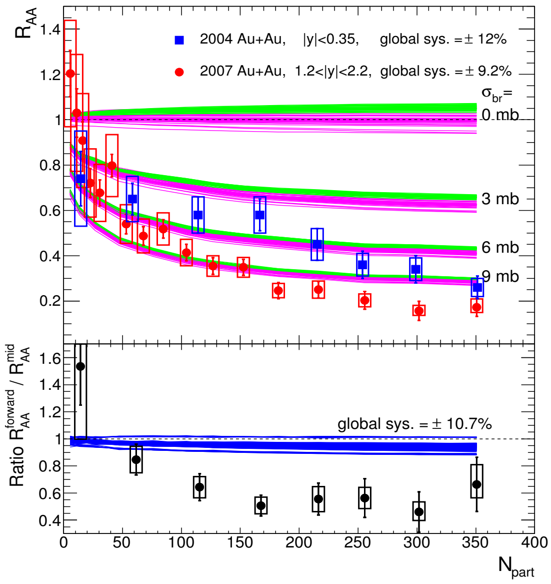

FIGURE 3. (Top) J/ψ R_{AA} at mid and forward rapidities. (Bottom) Ratio between forward/mid rapidity R_{AA}[5]. The curves are described in the text.

IMPLICATIONS ON THE MEASURED SUPPRESSION IN AU+AU COLLISIONS

A new measurement of the J/ψ R_{AA} at forward rapidity[5] based on data from 2007 has been released and is shown in Fig. 3, along with the ratio between mid and forward rapidities. This new measurement confirms the previous result[1] with increased precision and finer binning in N_{part}. Also shown as magenta(Green) curves in Fig. 3, are calculations based on EPS09 with an introduced linear dependence on the nuclear thickness + nuclear breakup with varying σ_{br} values for forward(mid) rapidity for each of the EPS09 nPDF parameter sets.

While a full description of the CNM effects across all rapidities in d+Au collisions, and their extrapolation to Au+Au collisions, is not yet available, some observations can still be made. In d+Au collisions, EPS09 with a linear dependence on nuclear thickness + $sigma_{br} = 4$ mb is in good agreement with the midrapidity data. Using this same description of the CNM effects extrapolated to Au+Au collisions, we see in Fig. 3 that there is suppression beyond even a breakup cross section of 6 mb for central collisions. This indicates that, at least at midrapidity, there is indication of suppression in Au+Au collisions beyond CNM effects. A similar statement can not be made at forward rapidity until a full description of the CNM effects in d+Au is available.

ACKNOWLEDGMENTS

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